Pyrometallurgical and Hydrometallurgical Research Equipment

Pyrometallurgy

- **Resistance Furnaces:**
  Our institute has several resistance furnaces at its disposal. Their set-up differs significantly from each other enabling suitable trial conditions for every research purpose. The equipment varies in terms of melt capacity (up to 35 l), atmosphere, maximum temperature (up to 2000 °C) and movability (static, tiltable, rotary).

- **Electric Arc Furnaces (SAF/EAF):**
  The institute possesses three electric arc furnaces in three different sizes. The smallest furnace has a volumetric capacity of 6 l. The medium furnace has a capacity of 12 l and can operate under controlled (inert/protective gas) atmosphere. Both lab-scale furnaces run on DC-mode and a power range of 1 - 100 kW. The funaces‘ set-up allows to perform experiments with or without a carbon crucible. The pilot-scale EAF has a transformer input of 1 MW, operates with AC or DC and offers a melting capacity of approximately 1 500 l.

- **Induction Furnaces:**
  IME owns seven hot and cold wall induction furnaces, each offering a specialty. Hence the furnaces can operate under defined atmosphere, pressure or vacuum (vacuum feeding/casting possible). The capacities range from 0.05 to 100 l.

- **Top Blown Rotary Converter (TBRC):**
  The TBRC is a very flexible and versatile furnace. It is heated via oxygen/air-gas burner, tilts and rotates around its own axis allowing a good temperature and chemical homo-genisation. The furnace can be fed via vibratory conveyors and offers the possibility of converting with an oxygen-lance. At IME, two different TBRC-vessel sizes are available (approximately 0.1 and 1 m³).

- **Microwave:**
  IME has the biggest microwave reactor of its kind. Eight 6 kW magnetrons heat up the material in a protective gas filled chamber (app. 700 mbar). A thermographic camera enables additional process surveillance. A continuous rotary reactor is planned to be installed in 2018.

- **Rotary Kilns:**
  The IME has three rotary kilns, which offer process temperatures up to 1500 °C. They vary in their tube diameter and material (ceramics or steel), feeding mechanism (dis-/continuous) and process atmosphere (protection gas or vacuum).

Hydrometallurgy

- **Hydro-Laboratory:**
  In the IME‘s hydrometallurgical laboratory it is possible to leach primary and secondary materials in a fume cupboard, in order to assure a safe treatment of volatile or dangerous substances. Leaching can be performed with acids or lye up to 5 litres of reaction volume. Magnetic or KPG-stirring can be provided during direct or indirect heating (water/oil bath or double wall container). The IME has the opportunity to perform experiments with feeding gas (e.g. N_2, Ar, O_2) and under the influence of ultra-sonic waves or microwaves. Process temperature, pH, redox potential and oxygen concentration measurements are essential and ensure reaction parameter control, kinetic studies and evaluation of chemical behaviour.

- **Multi-Step Leaching Cascade:**
  The IME is equipped with a pilot scale cascade leaching facility containing four stirred glass reactors (3 x 10 l, 1 x 8.5 l). Cascade leaching is a multi-step method. It involves the use of aqueous solutions containing a lixiviant which brings valuable metals into solution from ores or other leaching substrates. In the following steps, pH and concentrating agent are controlled to remove dissolved metals from the solution as selectively as possible. Online pH measurements and pumps, continuous and automatic feed of neutralizing agent (max. 4.5 l/h) are available. The maximum solution throughput is 10 l/h.

- **High-Pressure Autoclave:**
  The application of high-temperature leaching in an autoclave is definitely the best way of overcoming slow kinetics. Its main characteristics are the ability to shorten reaction times and raise extraction yield. The IME has two reactors with an online sampling system and on-line dosage equipment. The trail vessels‘ volumes are 1.0 and 10 l, the maximum operating pressure and operating temperature are 200 bar and 300 °C. Additionally, the reactor is equipped with a cooling device in order to control the occuring reactions.

- **Filter Press:**
  Filter presses are necessary for solid-liquid separations in hydrometallurgical large-scale tests. The equipment at our institute has four chambers with a dimension of 300 x 300 mm. Different capacities are available depending on the slurry volume. The stirred slurry container has a volume of 250 l and can reach operating pressures of 6 bar.

- **Heap Leaching Columns:**
  Heap leaching is a cost effective process for the extraction of metals (e.g.Cu) from ores. By addition of adequate additives, the metal extraction from the ore can be enhanced which leads to an improved yield and kinetics of the process. The IME column leaching equipment can be used for experimental process modeling and testing of innovative additives. Furthermore, the elution behavior of slags can be easily simulated before their application in road construction or

Our Commitment

Metallurgical products are constantly increasing in complexity and undergo a steady process regarding their composition in order to meet the growing requirements of the industry and application side. Therefore, continuously changing products require tailor-made solutions. Aside, high economic values and restricted availability of particular waste material components, as well as rising disposal costs and increasingly stringent environmental regulations are some of the many reasons for the quest and realization of recycling knowhow and technologies.

Our *Institute for Process Metallurgy and Metal Recycling* hence regards it as our task and duty to develop and provide solutions to overcome today’s challenges in metallurgy. We offer literature research, state of the art studies, thermochemical modeling, technical advice and survey service based on our profound experience in both hydrometallurgical and pyrometallurgical methods. Additionally, we are specialized in application-oriented research and development of innovative, cost-efficient and sustainable processes from lab-scale to pilot-scale. Our experimental work is not only dedicated to established processes and techniques but also considers novel approaches such as microwave technology applications.
If you would like to know more about us, please visit our homepage or find us on *ResearchGate*.

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Date 07/17

Recycling of Metals

IME Metallurgie Prozesstechnik Recycling

DIE METALLURGEN

- **Fundamentals / Slag Design**
- **Physical / Thermal Conditioning**
- **Pyrometallurgy / Hydrometallurgy**
- **Pilot Scale**

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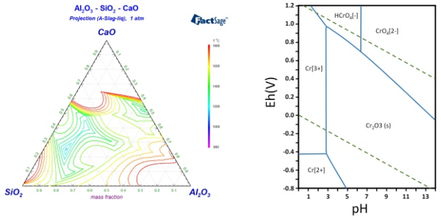
IME Research Areas in Recycling Metallurgy

Thermochemical Modeling

In order to design effective recycling solutions - and for safety reasons - it is essential to understand and predict the occurring processes in advance. We use the commercial software FactSage™ for thermochemical modeling. For pyrometallurgical purposes it enables us to predict equilibrium phases, melting temperatures, vapor pressures, favorable reactions, etc. For hydrometallurgical applications, simulations of E-pH-diagrams are possible, which are helpful to estimate necessary parameters for leaching and precipitation experiments.



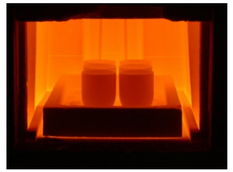
Pre-Conditioning

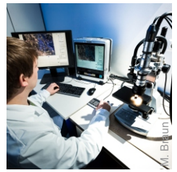
Most materials require pre-conditioning of physical or thermal nature to make it applicable for subsequent hydrometallurgical or pyrometallurgical treatments. Powdery input material (e.g. ore concentrate, off-gas dust) must be compacted prior to metallurgical treatment in furnaces, for example EAF, TBRC or rotary kilns. This can be done via pelletizing, cold briquetting, pressing or sintering. All the listed methods are available at IME. In this step, necessary additives such as slag formers or reductants are preliminarily mixed with the raw material.

Some metallurgical processes need preliminary thermal treatment with the objective of (partial) reduction of oxides, selective evaporation of specific metals and/or compounds as well as the removal of organics via pyrolysis. By using defined atmospheres like hydrogen, nitrogen, air or even vacuum; the chemical reaction can be controlled towards the desired direction.

Fundamental Research

As input materials become more and more complex, suitable data for thermochemical modeling is sometimes missing and requires systematic experimental investigation. Pyrometallurgical fundamental research is generally carried out in lab-scale and aims at the definition of metal/slag equilibria, evaluation of crucible material, determination of necessary process duration, investigation of the influence of melt movement, etc. These experiments can be performed under controlled atmosphere, online weight recording and temperatures up to 2000 °C. At IME, resistance and induction heated furnaces are most commonly used for fundamental research trials.



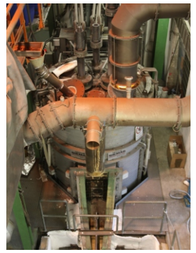


Hydrometallurgical fundamental research focuses on the determination of suitable leaching reagents, which are decisively responsible for the successful and selective recovery of the desired metal. Our work includes with the optimization of process parameters (e.g. pH, temperature, stirring speed, concentrations, etc.) and the investigation of effects of ultra-sonic and microwaves on leaching processes.

SAF/EAF-Metallurgy

Submerged and open arc furnaces respectively are widely used for primary metallurgy of ferro-alloys or recycling of iron scrap. For reasons of flexibility (high temperatures possible, mode of electrical operation, electrode positioning, etc.) the electric arc furnace is increasingly used for non-ferrous recycling purposes, few of which are listed below:

- recycling of NiMH and Li/Co-batteries
- recovery of precious metals from spent catalysts
- recovery of Cd/In/Ga from solar panels
- recovery of Fe/V/Ga from red mud



Microwave-Metallurgy

Microwave technology is quite new to metallurgy. Consequently, the occurring interactions between a matter and a microwave are not fully understood yet. Depending on a substance's properties, it can reflect or transmit a microwave or be stimulated by either the magnetic or electric field of a microwave. This results in innumerable recycling applications yet to be discovered. Alternative recycling routes for thin-layer solar cells and pyrolysis of WEEE have been investigated successfully by IME.

Bath-Smelting/TBRC

Some processes are not suitable for induction furnaces or electric arc furnaces due to inability to couple with the magnetic field, high turbulence generated in the melt or localized high temperatures. Settling processes of metal containing slags as well as aluminum recycling under salt are perfect examples which require unagitated melt movement. For these conditions resistance heated or gas fired furnaces are the only option.

Unfortunately, most furnaces show a lack of the desired (non-turbulent) stirring effect which favors coagulation of the metallic content. For that purpose, the IME offers a lab-scale, medium-scale and pilot-scale solution. They all base on the same principle: A vessel which rotates around its own axis and is adjustable in its tilting angle. The lab-scale unit is resistance heated while the medium- and pilot-scale furnaces (TBRCs) are heated by an oxyfuel-burner, achieving a good reproducibility of industrial processes.

Due to the TBRC's high flexibility, it is not exclusively used for metal/slag interaction processes. For instance, an applicable oxygen-lance enables converting processes. Thus, our TBRC has been successfully used for various purposes. Some examples of application are given below:

- recovery of metal fines from oxidic residues
- separation of matte and slag phase
- recycling of contaminated scraps (e.g. UBCs)
- autothermic metal recovery from WEEE-scrap

Melt Treatment

Certain waste streams require a final melt treatment before the recycling circuit is completed. Gas purging is a common refining process which is able to lower soluted gas levels and influence melt composition. At IME for instance, research is conducted on the removal of titanium from aluminum via the use of reactive gases. A different method for refinement of metals with high volatile element concentration is vacuum distillation. Here, volatile elements are removed from a metallic melt by applying low pressures, therefore selectively vaporizing and condensing alloy components. Studies on the refinement of magnesium scraps and incineration ashes are currently under investigation at the IME.

Multi-Stage Leaching

Recycling materials may need a multi-step leaching process to achieve successful treatment, which for example inhibits gel formation. Our cascade line enables a continuous process with four different treatment steps, each showing different parameters (pH, temperature, stirring rate). Application examples are as follows:

- (metallurgical) waste water treatment
  (e.g. recovery of Cu, Ni, Fe from Cu-electrolyte)
- selective neutralization of acid mine water
  (e.g. recovery of gold and rare earth-elements)